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InSAR measurement across the Central Nevada Seismic Belt

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Abstract

The purpose of this project was to conduct and interpret measurements of surface displacements in the Central Nevada Seismic Belt using Interferometric Synthetic Aperture Radar (InSAR). We expected to see ground deformation related to post-seismic relaxation following the 1954 earthquake sequence and/or surface creep along the major faults in the area. We hoped that the InSAR data help to explain an apparent discrepancy between relatively high GPS-measured displacement rates across this region (5-10 mm/yr) and the relatively low geologic slip rates inferred from paleo-seismic data (2-4 mm/yr).

A range displacement map obtained by averaging multple interferograms each covering 5 to 8 years reveals about ~2 mm/yr of range decrease (uplift) in the epicentral area of the earthquakes. Reassesment of the existing GPS data confirms deformation in this area.

Introduction

Central Nevada was the location of some of the largest earthquakes in North America during the 20st century (Fig. 1). The 1915 M7.5 Pleasant Valley earthquake, the 1932 M7.2 Cedar Mountain earthquake, and the 1954 Rainbow Mountain-Fairview Peak earthquake sequence (4 M6.8-7.2 events during 6 month) were right-normal oblique-slip events (with different degree of strike-slip component) and ruptured a ~250 km long, non-continuous stretch of north-northeast trending range front faults in Central Nevada. The area is also known as the Central Nevada Seismic Belt (CNSB). The 1954 earthquake sequence started with the Rainbow Mountain and Stillwater events in July/August, followed by the Fairview Peak and Dixie Valley events in December. The largest earthquake of the sequence was the Fairview Peak event with a magnitude of

Figure 1: Location map of the Central Nevada Seismic Belt showing the large earthquakes of the 20st century and the area of the interferograms in Figures 3 and 4.

M7.2 and up to 3.8 meters of vertical and 2.9 meters of right lateral motion (Caskey et al.; 1996). The 1954 events together with the 1915 M7.5 Pleasant Valley earthquake and the 1932 M7.2 Cedar Mountain earthquake further north and south ruptured a ~300 km long stretch of this ~N15E striking Central Nevada fault system

There is an apparent discrepancy between geodetic and geologic estimates of deformation across this region. Campaign and continuous GPS measurements show 4-5 mm/yr relative displacement occurring across the CNSB (Thatcher et al., 1999; Wernicke et al., 2000; Bennett et al., 2002, Svarc et al., 2003). Paleoseimic data, however, show cumulative long-term slip rates of only 1-2 mm/yr across the active faults in the region (Bell 1999, Caskey 2001). A possible explanation for this discrepancy is that the geodetic measurements do not reflect long-term deformation rates but transient deformation such as post-seismic relaxation following the 20th century earthquakes (Wernicke et al., 2001, Hetland and Hager, 2003). In this project we used existing 1992-2002 SAR data to search for evidence for anomalous (transient) deformation in the CNSB.

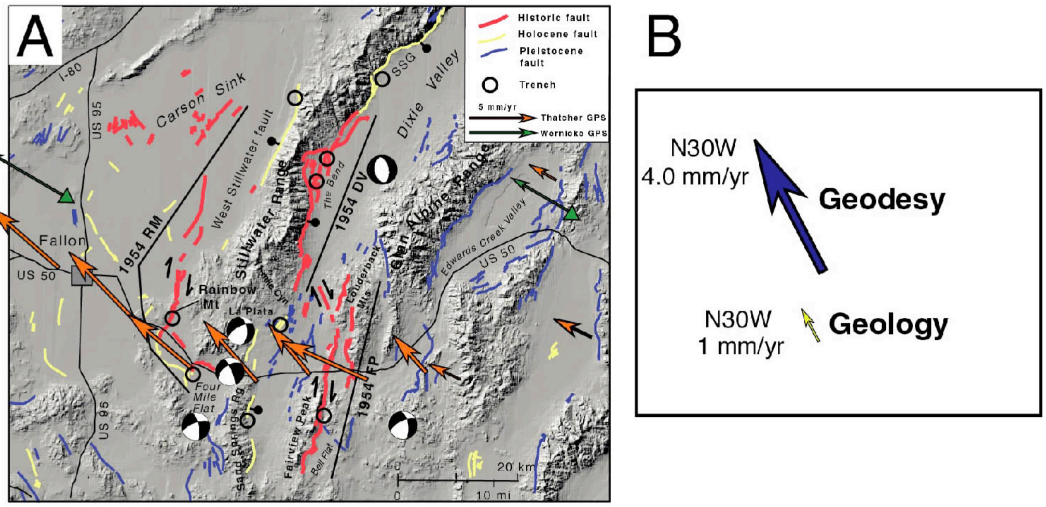

Figure 2: **A** Epicentral area of the 1954 earthquakes together with the GPS measured displacements of Thatcher et al., 1999. **B** Geodetic and Geologic estimates of deformation across the CNSB.

InSAR data

A preliminary, very precise ground displacement map obtained from InSAR supports the hypothesis that transient deformation is occurring in the CNSB (figure 3). The map has been constructed from a total of 76 SAR scenes by averaging (stacking) 9 independent interferograms (covering 4 conventional SAR frames), each spanning 4-7 years (total interferogram period 42 years). The map shows ~1.5 mm/yr range decrease in the area of the 1915 and 1954 earthquakes (between 39.4 and 40.8 latitude, green-yellow-red colors). We are confident that the measured range change is not a measurement artifact because similar interferograms stacks obtained from interferogram spanning a few days to a few month do not show any similar pattern. The observed range decrease may be caused by local uplift and/or east displacements. East-ward motion of the area east of the major is consistent with models of post-seismic deformation (Wernicke, 2000; Hetland and Hager, 2003).

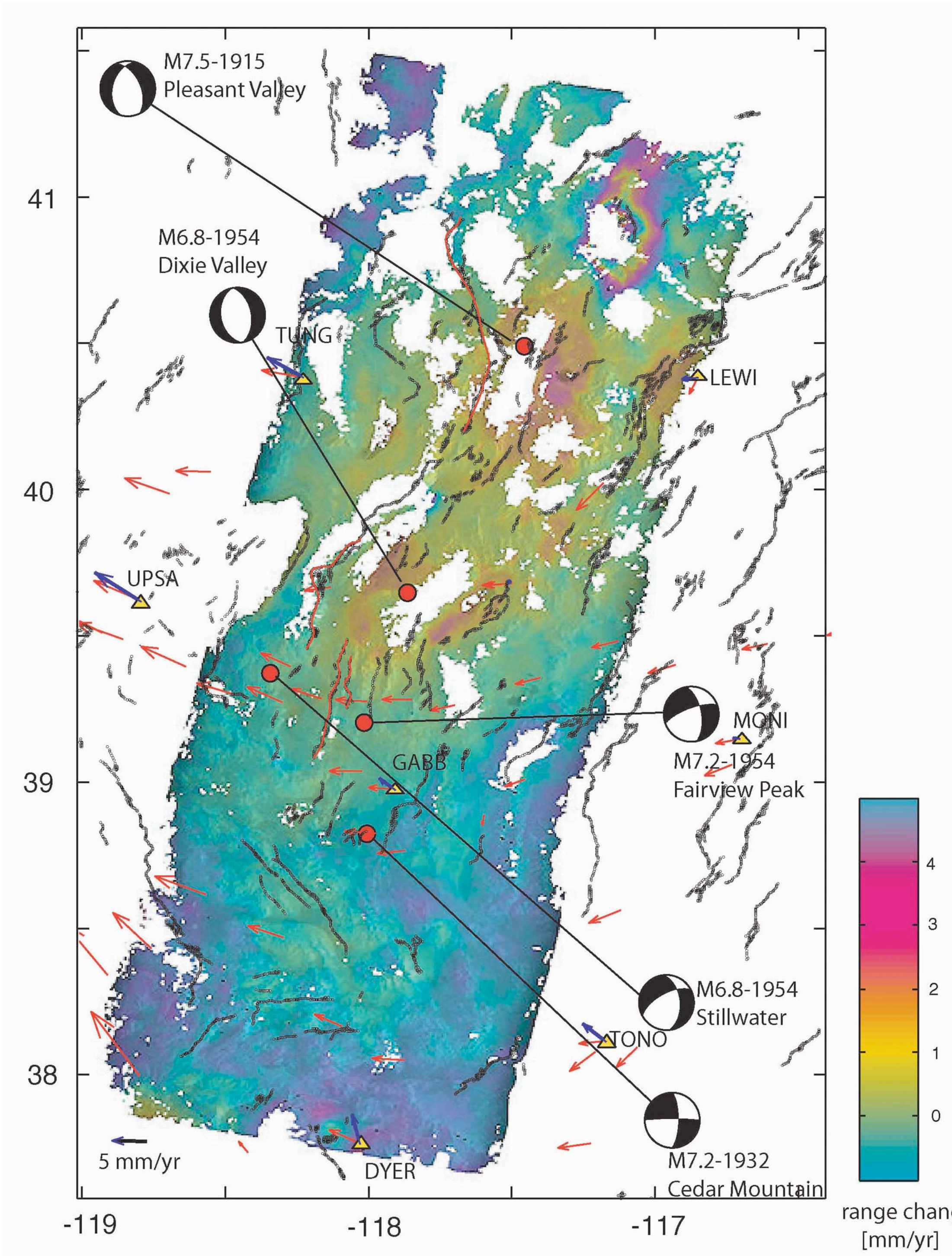

Figure 3: Preliminary interferogram of the Central Nevada Seismic Belt, constructed by averaging eight 5-8 year interferograms. The phase signature in the northwest represents land subsidence cause by ground water extraction in the Red House, Nv. Area. The measurement precision of the interferogram is ~0.5 mm/yr. The GPS measured displacements (BARGEN permanent sites (blue) and USGS campaign sites (red)) are show with respect to station MONI.

Anomalous deformation in this area of the CNSB is confirmed by GPS measurements. Figure 3 shows campaign GPS measurements (obtained from the USGS website) and permanent GPS measurements from the BARGEN network, both with respect to station MONI which is located ~100 km east of the CNSB (Fig. 3). The campaign GPS measurements suggest some sort of flow around the epicentral area of the 1954 earthquakes. The stations along highway 50 in the east of the figure have a displacement component towards the south (with respect to station MONI) whereas the stations in the west of the figure have a displacement component toward the north. It is interesting to note that station LEWI, which anomalous motion has been discussed by Wernicke (2000) is located in the area of InSAR detected range decrease.

Precision of InSAR measurements. The main error sources in InSAR ground displacement measurements are atmospheric heterogeneities and uncertainities in the satellite orbits. The atmospheric error of a typical Basin and Range interferogram is ~1.2 cm, corresponding to a velocity error of 2 mm/yr for a 6 year interferogram (Amelung et al., 1999; Amelung and Bell, 2003). Averaging N interferograms reduces the error by 1/sqrt(N) (assuming Gaussian noise). The error of the map in Fig. 3 thus is ~0.6 mm/yr. Similar measurement precisions have been reported for interferogram stacks by Peltzer et al, 2002) and Fialko et al. (2001).

Errors of the satellite orbits result in linear phase ramps of typically 1-2 phase cycles (3-6 cm) across an interferogram. Orbital phase ramps are not Gaussian distributed and therefore not removed by averaging multiple interferograms (Hanssen, 2001). In Fig. 3 we have removed phase ramps assuming there is no relative displacements between the egdges of the interferograms.

The 1994 M5.9 Double Spring earthquake.

We also conducted a study of the 1994 Double Spring Flat earthquake (Amelung and Bell, 2003). This was the largest earthquake to struck Nevada in the last 30 years. The epicentral area is located ~150 km west of the Central Nevada Seismic Belt (Figure 1).

Descending and ascending ERS interferograms show a maximum range change of 8.5 cm which is the coseismic ground displacement associated with this normal, oblique-slip, moderate-sized earthquake (Fig. 4). Elastic inverse modeling and surface displacements across coseismic ground cracks suggest that two different event sources could account for the observed deformation. The first source was the mainshock with right-oblique slip on the north-northwest striking DSF fault. The second source was normal faulting on a shallow, north-northeast striking, elongated plane (conjugate to the DSF fault). These two sources are consistent with the pattern of post-event seismicity and we suggest that the second source represents seismic and aseismic slip triggered by the mainshock. Calculations of changes in Coulomb failure stress show that the mainshock encouraged normal slip on this plane. This result is in contrast to the interpretation of seismic data which indicated left-normal oblique slip on a north-northeast striking fault (Ichinose et al., 1998).

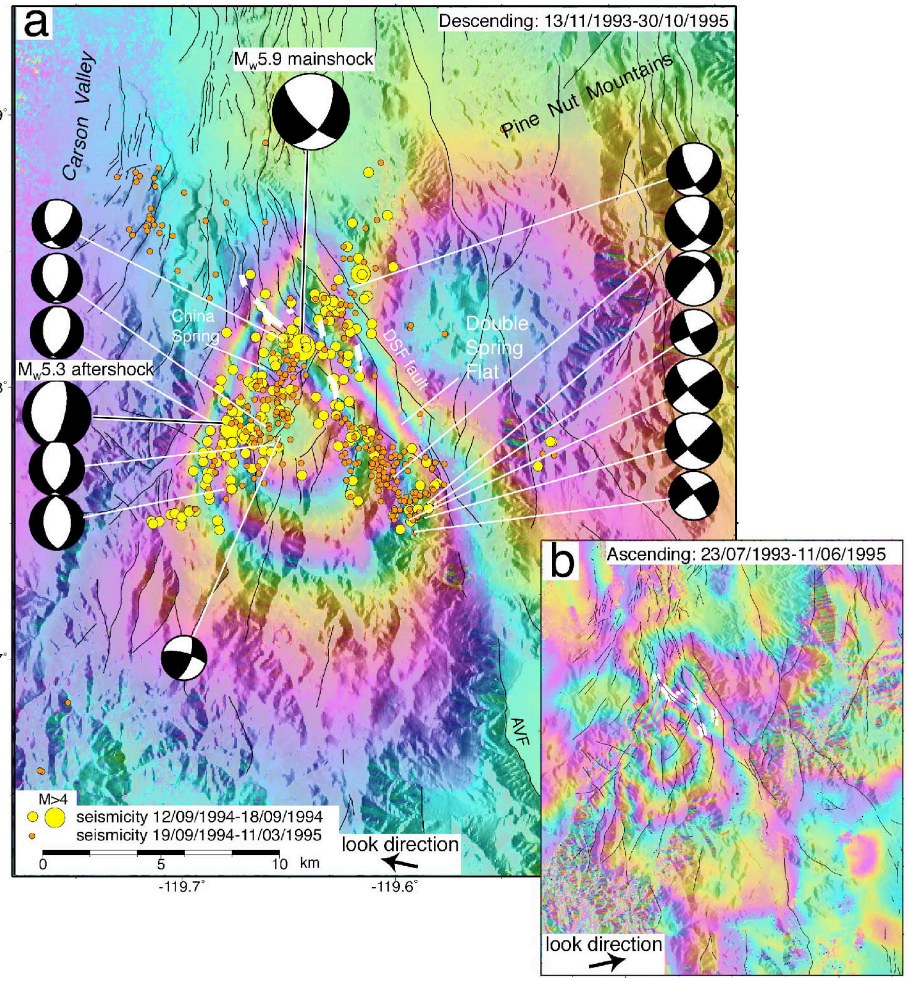

Figure 4. Ground-deformation, aftershock locations and focal mechanisms of largest events associated with the 1994 Double Spring Flat earthquake sequence. Wrapped phase of **a** descending and **b** ascending 1993-1995 interferograms. One colorcycle represents 2.8 cm range displacement. The aftershocks follow two conjugate trends with the first week of aftershocks (yellow) primarily along north-northeast. Co-seismic ground cracks are shown by white lines. Aftershock locations and waveform-derived focal mechanisms are from *Ichinose* [2000]. From *Amelung and Bell* [2003].

Conclusion

We used InSAR to measure ground deformation in the Central Nevada Seismic Belt. A high-precision range displacement map obtained by averaging 8 interferograms indicate range change rates of 1.5 mm/yr in the eipcentral area of the 1915 and 1954 earthquake. The measured range change is most-liekly caused by post-seismic relaxation following the earthquakes.

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